International Journal of Evaluation and Research in Education (IJERE)
Vol. 14, No. 6, December 2025, pp. 4443~4455
ISSN: 2252-8822, DOI: 10.11591/ijere.v14i6.33960

Evaluating mathematics teachers' usage of online tools to enhance learning performance of high school students

Olajumoke Olayemi Salami, Erica Dorethea Spangenberg
Department of Mathematics, Science and Technology Education, University of Johannesburg, Johannesburg, South Africa

Article Info

Article history:

Received Dec 8, 2024
Revised Aug 22, 2025
Accepted Sep 30, 2025

Keywords:

Evaluation
Fourth industrial revolution
Learning
Mathematics
Online tools

ABSTRACT

The application of digital technologies to teach mathematics is increasing and how educators use these tools and their impact on the performance of students needs to be sufficiently researched. In this study, we explore middle school mathematics teachers' utilization of Algebra Nation (AN), an online instructional resource, to supplement instruction and improve the performance of their mathematics students, particularly in algebra. A survey was conducted involving 596 teachers and a quasi-experimental trial. We examined the relationship between AN use and Algebra I end-of-course (EOC) exam performance. The findings showed that engagement in AN observed through student login, video watches, and professional teacher development is associated with improved student's success rates in mathematics. This study also revealed that challenges such as digital disparity, data privacy issues, and professional teacher development were identified to impact the effective implementation of digital technologies in teaching mathematics. This study recommends that there should be systematic integration of web resources, combined with targeted teacher training to significantly enhance mathematics instruction. These conclusions inform future technology adoption and policymaking, with emphasis on equal access and systemic teacher support.

This is an open access article under the CC BY-SA license.

Corresponding Author:

Olajumoke Olayemi Salami
Department of Science and Technology Education, University of Johannesburg
Johannesburg, Gauteng, South Africa
Email: olajumokes@uj.ac.za

1. INTRODUCTION

The fourth industrial revolution, characterized by the rapid advancement regarding electronic device and their integration into every aspect of society, is reshaping the landscape of education [1]. In this transformative era, mathematical education stands at the forefront, tasked with preparing students to thrive in an increasingly digitized world. Traditional approaches to teaching and learning mathematics are being reexamined as educators seek innovative strategies to harness the potential of emerging technologies [2]. This sets the stage for exploring the evolving paradigm of mathematical education in the age of the fourth industrial revolution, emphasizing the use of online resources to improve educational results [3]. By examining the intersection of mathematics education and digital innovation, we can gain insights into how educators are adapting pedagogical practices to accommodate students' changing needs in the age of technology [4], [5]. The integration of online tools into mathematical education offers unprecedented opportunities to engage learners, personalize instruction, and foster deeper conceptual understanding. Interactive platforms, virtual simulations, and adaptive learning algorithms provide students with dynamic possibilities for education catered to their unique requirements and educational preferences [6].

The incorporation of online resources has completely changed the educational environment in the current technological age, particularly in the realm of mathematics [7]. In addition to keeping students interested, these resources provide dynamic and interactive platforms that improve their comprehension and competency in mathematical ideas. This investigation explores the various ways that online resources are being used to enhance mathematics education. The capacity of online resources to offer individualized learning experiences catered to each student's unique requirements and learning preferences is one of its main benefits. Students can study mathematical ideas at their own pace with the use of interactive tutorials, virtual manipulatives, and multimedia materials, which strengthen comprehension through practical application [8]. Real-time assessment and feedback are made possible by the adaptable nature of many online programs, which helps teachers pinpoint students' areas of difficulty and offer them focused support. Teachers can monitor student progress, identify misconceptions, and tailor instructional interventions to meet individual learning needs by utilizing algorithms and data. Regardless of their geographical location, students can participate in peer-to-peer conversation and problem-solving activities thanks to online tools that support collaborative learning experiences [9]–[11]. Beyond the typical classroom, online classes, discussion boards, and group projects enhance educational opportunities by fostering a feeling of community and group learning.

Understanding important factors like digital equity, data privacy, and teacher preparedness is essential when incorporating online resources into mathematics instruction. To prevent learning inequalities, it is essential to guarantee that every student has equitable access to technology and a dependable internet connection [12]. In order to successfully integrate digital tools into their classrooms, educators also need to receive adequate training. To give teachers the know-how to maximize online resources for improved student learning, professional development programs emphasizing digital literacy, instructional tactics, and technological abilities are essential. Digital resources can help students become more involved, customize their education, and develop a deeper comprehension of mathematical ideas [3]. By using these resources, teachers may provide inclusive, dynamic learning environments that help students thrive in math and other subjects. Initiatives like the no child left behind act and the creation of academic standards have raised the pressure to raise student success. Standardized testing is frequently used to gauge student performance in schools, especially in math-related courses. The results may have an effect on administration, personnel, or funding [13]. Teachers have looked for classroom materials and professional development to improve education in response to these high-stakes testing contexts. Although studies indicate that technology can improve learning and assist in teaching mathematics [14], [15], not every teacher uses these techniques right away, and they do not always lead to appreciable gains in student performance. The interactions between technology, instructional strategies, student involvement, and instructional materials require further research. As the educational system adapts to the demands of the fourth industrial revolution, this is particularly crucial. In an era of rapid educational change, this article examines how math teachers employed an online algebra tutoring platform and how it impacted their students' performance on standardized tests.

Despite the fact that many students find mathematics difficult, it is seen as an essential component of K–12 education and a prerequisite for success in postsecondary education [16]. In particular, higher professional earnings, graduation rates, and college admission have all been associated with high school algebra completion [17]. Since mathematics is a necessary subject for success in the future, standardized tests are significant. These assessments are now a crucial component of the modern educational system, being used to compare national and international school results, assess the efficacy of teachers, and monitor student progress. Concerned about their students' poor performance, many educators are searching for instructional resources to help their pupils improve their ability to reason and comprehend mathematical ideas. Strategic technology integration can greatly improve mathematics instruction, even though not all technological instruments are successfully accepted or have strong teacher support [18], [19]. It provides students with worthwhile chances to delve further into mathematical ideas [20]. Although teachers can use a wide range of technologies to aid in their instruction, the focus of this study is mostly on online math resources, which are web-based tools designed specifically for math instruction in the wake of the fourth industrial revolution. While word processors and calculators are examples of educational technology, this study focuses exclusively on online platforms. According to research, numerous strategies are employed to integrate online math resources into the classroom, which has a range of impacts on students' performance. An overview of some of the most significant research on the impact of technology on student results and the usage of digital tools by math teachers in the classroom is provided in the sections that follow. Research on how technology affects students' performance in secondary mathematics, with an emphasis on the ways in which various methods affect performance, includes [21]–[25]. The study that relates to the use of technology by teachers can be found in Chiu [26]. Other studies [27], [28] also found that student-centered, interactive video lessons, which encouraged collaborative problem-solving, resulted in significantly better mathematics problem-solving skills compared to teacher-centered instruction. Several studies [29]–[32] revealed that simply substituting technology for teacher instruction did not guarantee better results.

This study aims to provide a level of consistent, structured artificial intelligence (AI) integration across classrooms is a significant data point and shows a broad institutional shift toward AI-enabled instruction—which is not always documented at this scale in the literature. The novelty in the current study can be summarized: i) the current study reflects a blended learning innovation, blending passive and active strategies in a single lesson often not accommodated in literature; ii) provides a real-world implementation of adaptive teaching practices aided by AI, and not just theoretical; iii) provides a pedagogical shift towards student-centered classrooms, where AI is not just a content delivery tool but a classroom management strategy and learning support; and iv) the study showcases AI's extended instructional role beyond the classroom, something not widely documented. Lastly, the study quantified the effect of teacher-initiated activities on student performance, which is not often examined in the literature.

2. THEORETICAL FRAMEWORK

Understanding how teachers use technology in the classroom and how it impacts students' comprehension is challenging. Several theories of instrumentation [25], [33], [34], and instrumental orchestration [35] have become more and more important in mathematics education to comprehend how instructors and learners engage with technology to learn mathematics. According to instrumentation theory, for students to learn how to interact with a technological tool or artifact, they must go through a process called "instrumental genesis", in which they must devise strategies and methods for using the tool to transform it into an instrument [29], [35].

Instrumental orchestration, the term used to describe the role of the instructor in guiding the usage of technology by learners, has emerged to support students' instrumental genesis. Teachers' designs and implementation of learning activities centered around these tools are essential [36]. Smale-Jacobse *et al.* [37] highlighted two critical elements to consider when using technology in mathematics instruction: ways of utilization and didactical arrangements. "Didactical configuration" refers to how the teaching environment and tools are arranged in the classroom, while "exploitation mode" describes how teachers utilize these setups to meet their educational objectives. These concepts help explain the strategies educators adopt to facilitate student learning in mathematics.

For instance, Vita *et al.* [35] presented a model called "technical demo", where a teacher demonstrates a tool's functionality (exploitation mode) by walking students through the steps and projecting the tool on a screen (didactical configuration). Though this approach is common, other orchestration types also exist and offer various ways for teachers to incorporate technology in mathematics education. In this context, instrumental orchestration was used as a framework to interpret how teachers incorporated Algebra Nation (AN) in mathematics classes. This study explored different configurations, such as individual remediation or group learning, and how various orchestration types were applied to teach algebraic concepts. While it is understood that educators use diverse didactical methods and exploitation modes [38], this research provided an overview without delving deeply into every orchestration's nuances.

This study focuses on the AN online tutoring platform, designed to help both teachers and students meet the Nigerian mathematics state standards, particularly those required for passing the Nigeria Algebra I end-of-course (EOC) exam. The Algebra I EOC is a standardized assessment mandated for every student enrolled in Algebra I in public schools, measuring their mastery of the Nigeria Algebra I standards. For the 2022–2023 academic year, students were required to complete 20–25 open-ended questions and 30–35 multiple-choice questions within a 60-minute timeframe.

At the time of AN's introduction, Nigerian teachers had already been implementing the Nigeria Standards, also known as the Common Core State Standards for Mathematics, for at least 3 years, following their adoption by the state in 2021. The online resource included practice exams that were modeled after the Algebra I EOC, video lessons by seasoned algebra tutors, and an interactive, synchronous wall where students may talk about algebraic ideas with teachers, other students, and online tutors, as presented in Figures 1 and 2. The movies were also accompanied by a workbook with study tips for both teachers and pupils. A variety of instrumental orchestration types are shown in Table 1.

The following domains arranged each of these components' content: i) linear equations, functions, and inequalities; ii) exponential functions; iii) algebraic expressions; iv) an introduction to functions; v) single-variable statistics; vi) quadratic functions; vii) a summary of functions; and viii) 2-variable statistics. The content was developed in accordance with Florida's algebra state standards. Some design parallels exist between AN and other popular online resources like ALEKS, Khan Academy, PLATO, and Cognitive Tutor. These internet sources offered state-standard-aligned video tutorials on mathematics topics and brief formative assessment questions that allowed students to gauge their progress. Like AN, cognitive tutor gives students workbooks that are printed and correspond with their online lessons. While all the resources have modules corresponding with the nine algebraic domains of AN, calculus, geometry, trigonometry, and introductory mathematics are among the most extensive topics covered by Cognitive

Tutor, Khan Academy, PLATO, and ALEKS. While AN does not have adaptive technology and is a self-paced platform, other online resources use adaptive learning environments to provide individualized education. Despite this, AN has set itself apart for a number of reasons. Teachers and students can use it for free, is specifically aligned with Nigeria's national standards and EOC examination and offers on-site professional development sessions led by experienced educators. The inquiry-based professional development enables teachers to explore AN's features, such as video tutorials, practice exams, interactive student discussion forums, and workbooks. These resources comprehensively cover Algebra I topics, and teachers are trained in various instructional strategies, such as flipping the classroom by assigning videos for homework, segmenting videos for classroom use, or incorporating them as co-teaching tools during lessons. As they watch the videos, the students always complete the workbook as part of these strategies. More than 100,000 students statewide swiftly embraced AN after it was made available to all Abuja schools as a free resource during the 2022–2023 academic year. Numerous training sessions and professional development days have been held throughout Abuja to promote educators' use of this technology. Furthermore, AN rapidly develops into a resource for instructors and students as well as a cooperative online community of educators. A professional development program has been set up to allow educators to share teaching resources, watch videos of Abuja classroom teachers using successful mathematical teaching techniques, and have conversations about teaching mathematics and getting ready for the Algebra EOC. This initiative mirrors the interactive wall and video tutorial features available to students.

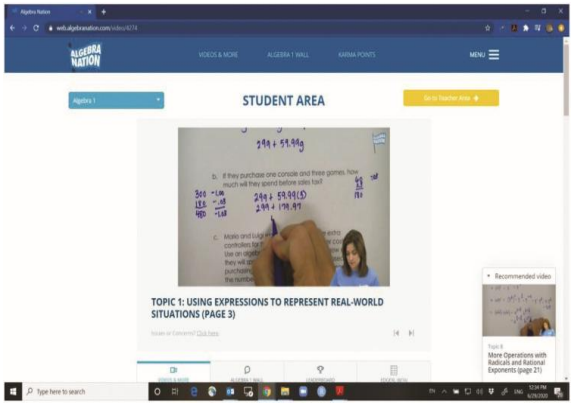

Figure 1. Example of a teaching video for AN

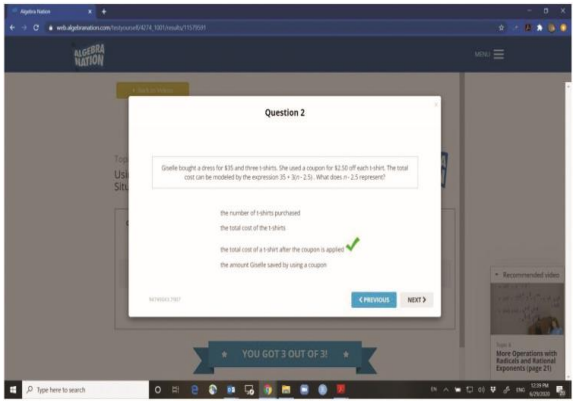

Figure 2. Example test-yourself worksheet for AN

Table 1. Various types of instrumental orchestration [35]

SN	Orchestration type	Example
1	Technical demonstration	The teacher projects the technology tool onto the screen and walks students through its technical steps.
2	Describe the screen	A teacher demonstrates a mathematical concept on a screen using a technological tool.
3	Connect-screen-board	The teacher draws connections between math and other on-board representations using a tool to explain mathematical concepts.
4	Talk about the screen	Using a tool projected onto the screen, the teacher guides the discussion of a mathematical concept.
5	Spot-and-show	The teacher uses a technological tool to identify the student's work for the project and starts a conversation about a mathematical concept.
6	Working as a Sherpa	Students share their work with the class using technology while the teacher guides the discussion of mathematical ideas.
7	Work-and-walk-by	Students use their gadgets for individual technological use while the teacher moves around and works one-on-one with each student.

3. METHOD

The goals of this study are to comprehend how educators are using AN, an online mathematics resource, to engage students and the connection between AN use in the classroom and algebra performance. Specifically, the following research inquiries will be tackled:

- What aspects of instruction are AN incorporating?
- Does increased student performances on the EOC for Algebra I correlate with the use of AN in the classroom?
- Did the schools where teachers engaged in in-person professional development, utilized the AN online learning platform, and ordered workbooks for students and teachers exhibit different mean student scores and pass rates on the 2023 Algebra I EOC compared to those that did not incorporate AN?

3.1. Sample

This study gathered data from four primary sources: the National Center for Education Statistics (NCES) website, the Nigeria Department of Education website, the AN system, and the "how teachers use AN" survey. During the 2022–2023 school year, 596 Algebra I teachers in Abuja participated in a quantitative and qualitative survey to answer research question 1 (RQ1), indicating a response rate higher than the norm for online surveys [22].

For research questions 2 (RQ2) and 3 (RQ3), data from the AN system captured usage across two academic years, including login and video view counts, responses to questions, and discussion forum contributions. Because the Algebra I EOC exam is a requirement in Nigerian education, attention was focused on middle and high school data. Additional EOC results for 2021-2023 and related school-level data were gathered from the Florida Department of Education and NCES websites.

A quasi-experimental analysis for RQ3 assessed schools' performance based on Algebra I EOC mean scores and passing rates. Key factors included AN system login, teacher training, and workbook access. The average treatment effect (ATE) was calculated by comparing matched treatment and control groups: Compared to 73 schools without teacher logins, workbooks, or training, 291 schools had teachers actively using AN. This technique took into consideration group differences and used a quasi-experimental design to lessen the impact of uncontrollable variables [39].

3.2. Quality measures

The purpose of the survey used to answer RQ1 was to investigate how teachers and students use AN for various instructional levels. It asked about their use of the workbook, test questions, discussion board, and AN video, including how, where, and how often they used them. There were 3 open-ended questions and 39 closed ended, yes/no rating scale or yes/no questions in the survey. This survey followed best practices outlined by Yedilbayev *et al.* [40] to ensure question clarity. Closed-ended questions used precise frequency options, such as "in every class" or "1 or 2 times in every five classes," to avoid ambiguous terms like "frequently". Open-ended questions addressed AN strengths, weaknesses, and usage limitations.

The questionnaire was pretested, including expert evaluations, cognitive interviews, and pilot research, guided by Park *et al.* [41]. The 14 cognitive interviews, split between think-aloud and verbal-probing sessions, involved experienced algebra teachers. Additionally, expert feedback from 3 mathematics educators and AN coach led to revisions. In the pilot with 100 teachers, a 42% response rate helped identify and revise unclear questions.

RQ2 and RQ3 examined Algebra I EOC exam passing rates and average scores for spring 2024. Standardized passing scores were set by the Nigeria Department of Education. controlled covariates included previous passing rates, student-teacher ratios, percentages of pupils who qualify for free or reduced-price meals, as well as markers for title I, charter, or magnet schools. The NCES and the Nigerian Department of Education provided the data.

3.3. Analysis

The study analyzed the application and impact of AN across various school settings. For RQ1, frequency counts revealed diverse AN usage among teachers, with instructional videos and individual assignments being the most common. Open-ended responses were analyzed to understand the types of instructional methods, confirming that teachers frequently employed a "screen-centered" orchestration to reinforce algebra concepts.

For RQ2, the study examined how AN use indicator related to algebra EOC pass rates, incorporating a regression analysis with variables such as teacher usage, training, and workbook orders. A latent profile analysis (LPA) grouped schools based on six AN usage indicator-student logins, video views, and workbook ratios, among others—to identify usage patterns and their impact on pass rates. Results showed that schools with higher AN engagement tended to have better pass rates on the Algebra I EOC assessment.

In addressing RQ3, a propensity score analysis (PSA) was employed to balance covariate distributions between schools using AN and control schools. Using a genetic algorithm, schools were matched based on 10 covariates, achieving acceptable covariate balance per what works clearinghouse (WWC) standards. After matching, the ATE for Algebra I EOC pass rates was calculated, and additional regression adjustments were applied where needed to account for covariate imbalances. The Abadie-Imbens method [42] provided standard errors and bias adjustments, ensuring reliable estimates of AN's impact on student outcomes.

4. RESULTS AND DISCUSSION

The survey findings for RQ1 indicated that educators employed all facets of AI in diverse manners to equip students for the EOC test for Algebra I. The 76% of educators indicated utilizing AN in the

classroom at least biweekly, while 56% reported presenting instructive films to their students at least weekly. Educators valued the adaptability offered by AN, enabling them to "play a video and circulate within the classroom" or "pause it for mathematical discussions." The films provided explicit and succinct education, examples, and practice in algebraic topics.

Educators valued the flexibility offered by AN, enabling them to "play a video and circulate around the classroom" or "pause it for mathematical discussions." They assumed the films would serve as a good beginning point for teaching the content in their own terms. Many teachers were sure that viewing the films would serve as an excellent beginning point for delivering the content in their own terms. Additionally, 60% of teachers reported providing homework where students worked independently on the AN website during class. The 79% of teachers asked students to log onto AN using classroom PCs, however other devices such as tablets, cell phones, and computer laboratories were also employed. Teachers commented that using the AN platform helped support student-centered, modified classroom learning plans that better suit a work-and-walk learning approach. They underlined the necessity of pupils being able to work independently, as it allowed the instructor to "move around the room to check for understanding." The 34% of instructors reported setting up learning centers with AN, a version of the work-and-walk-by strategy. Educators can see students using the AN platform to work alone or in small groups thanks to this system. Additionally, according to the survey, 56% of teachers assigned AN films as homework to students who were at danger of falling behind, and 79% of teachers used AN as a remediation tool. Another successful method was arranging tutoring sessions before or after school utilizing AN as a resource.

The variables explained 66.1% of the variation in the proportion of students who passed the Algebra I EOC in the 2013–2014 academic year, according to the school-level multiple regression results from the preliminary analysis of RQ2. Schools with algebra teachers who bought workbooks had a 6.78% greater passing rate than those without. An overview of the key factors affecting the Algebra I EOC success rates is given in Table 2.

Table 3 shows the key variables influencing Algebra I EOC passing rates in the spring of 2014. Prior passing rates had a significant impact, with the 2013 passing rate (β=0.596, $p<0.001$) being a stronger predictor than the 2012 passing rate (β=0.128, p=0.002). Workbooks accessibility also positively influenced passing rates (β=5.884, p=0.027), as did the presence of trained teachers participating in TYP challenges (β=0.008, p=0.033). Additionally, AN-integrated schools with trained teachers saw a notable increase in passing rates (β=4.251, p=0.014). However, a larger student population negatively impacted passing rates (β=-0.010, p=0.024), suggesting that resource allocation might contribute to the success of students.

The analysis proceeded in three steps. First, the optimal number of latent classes was determined through model fit indices. Then, the distribution of schools across these classes and the classification probabilities were calculated. Finally, differences in rates of passing the Algebra I EOC exam across the classes were assessed. Table 4 displays the fit indices used, comparing 2, 3-, and 4-class models. Given the rejection of the 4-class model by the LMR test and minimal variation in fit indices, the 3-class model was selected for detailed analysis.

Table 2. A summary of the important factors affecting the Algebra I EOC success rates

Variables	Estimate	Student error	Pr(>|t|)
(Intercept)	45.255	3.177	0.000
Average-based success rates 2012	0.128	0.044	0.002
Average-based success rates 2013	0.596	0.045	0.001
Mean-centered students count 2014	-0.010	0.006	0.036
Workbook's accessibility (yes or no)	5.884	3.094	0.027
Trained educators who took part in TYP challenges	0.008	0.005	0.033
Integrated schools with qualified teachers in AN	4.251	1.707	0.014

Note. TYP stands for "test yourself prepared"

Table 3. Fit metrics for models of latent profiles in competition

Model	Log-Likelihood	AIC	BIC	Entropy	LMR-A p-value
2 class	-26,120.011	53,260.028	54,396.977	0.875	<0.001
3 class	-25,588.286	52,527.351	53,580.853	0.863	0.009
4 class	-25,526.5986	51,953.395	53,151.417	0.861	0.109

Table 4. Class distributions and numbers for the 3-class structure

Latent classes	Counts	Proportion
1	654.081	0.460
2	536.005	0.452
3	103.903	0.088

The study grouped schools by AN usage into three categories: low usage (46% of participants), medium usage (45%), and high usage (9%), as presented in Table 5. In the low-usage group, students and teachers accessed AN less frequently, averaging 3.7 logins and 3.2 video views for students, while high-usage groups showed significantly more engagement, with students logging in up to eight times as often. Analysis of school pass rates showed that Algebra I EOC scores increased with higher AN usage, with passing rates at 63.3%, 68.9%, and 83.3% for low, medium, and high usage, respectively. The differences were statistically significant, affirming that greater AN usage aligns with better Algebra I exam results.

Table 5. The outcomes of the model of latent profiles

Latent class	Indicator	Mean (SE)	Variance
1 class	Access for learners	3.655 (0.138)	5.595
	Perspectives for pupil videos	3.184 (0.178)	9.747
	Access for instructors	9.172(0.850)	121.735
	Perspectives for instructors' videos	7.754(1.481)	142.683
	Ratio of the workshop's video views	0.560(0.070)	0.766
	Login ratio by workshop	0.731(0.084)	1.242
2 class	Access for learners	10.492(0.401)	40.402
	Perspectives for pupil videos	13.043(0.648)	117.971
	Access for instructors	41.993(2.119)	2,321.228
	Perspectives for instructors' videos	73.415(5.637)	40,374.367
	Ratio of the workshop's video views	9.381(0.262)	153.970
	Login ratio by workshop	7.911(7.911)	150.246
3 class	Access for learners	24.656(0.58)	117.971
	Perspectives for pupil videos		
	Access for instructors		2,321.228
	Perspectives for instructors' videos	215.482(45.651)	40,374.357
	Ratio of the workshop's video views	47.808(4.174)	153.970
	Login ratio by workshop	31.594(3.098)	150.246

Note: all means are statistically significance at $p<0.0001$

Table 5 shows that schools fall into three usage categories—low, moderate, and high—based on engagement with AN. Low-usage schools had an average of 3.655 access for learners and 9.172 access for instructors, while moderate-usage schools saw 10.492 access for learners and 41.993 access for instructors. High-usage schools demonstrated the greatest engagement, with 24.656 access for learners and a significant increase in access for instructors (2,321.228) and perspectives for instructors video views (215.482), indicating deeper integration of the platform into instruction.

Figure 3 shows the percentage passing for students in each latent class. The lowest percentage passing was in latent class 1 at 63% and the next lowest was in latent class 2 at 69%, while the highest percentage passing was in latent class 3 at 83%. This shows that more use of AN is associated with higher student performance.

In addressing RQ3, the findings of school matching using a genetic algorithm revealed that eight out of ten covariates were covariate equivalent, meeting the 0.05 standard deviation requirement. However, 2 covariates—the percentage of students eligible for free or reduced-price lunches and the average score on the 2013 Algebra I EOC assessment—did not meet this stringent requirement. According to the WWC criteria for quasi-experimental studies, these 2 covariates were adjusted in the regression analysis to estimate the treatment effects of schools that got the AN workbook and had teachers apply the AN system.

The ATE represented the expected difference in outcomes between control schools and AN treatment school that were matched by the genetic algorithm based on the same propensity score (PS). For the spring 2014 scale score, the ATE for schools receiving in-person teacher training, workbooks for students and instructors, and teaching via the AN online platform was predicted to be 2.91 (SE=1.3, p=0.02, Hedges' g=0.26). Furthermore, the impact on passing rates for spring 2014 was assessed at 5.46 (SE=2.28, p=0.02, Hedges' g=0.28). These findings imply that instructors' use of AN materials resulted in higher passing rates and mean scores in participating in schools.

The ATE study on mean scale scores revealed that students in schools where teachers used the AN system performed 0.26 standard deviations better on the Algebra I EOC exam than students in similar schools without AN support. Furthermore, the ATE analysis of passing rates revealed that schools with instructors actively utilizing AN had 5.46% better Algebra I EOC passing rates than comparable schools that did not use AN, resulting in a standardized difference of 0.28 standard deviations. According to the WWC guidelines, the results of AN adoption in schools are statistically significant and educationally relevant.

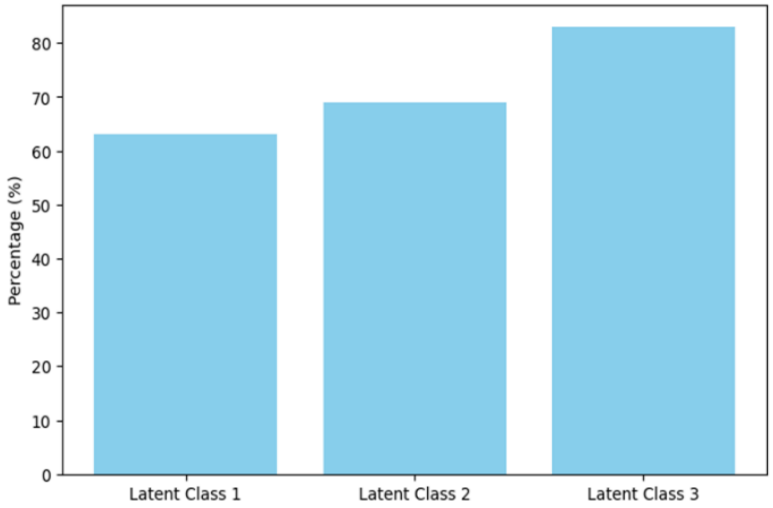

Figure 3. Mean pass rates for different use levels in schools

This study contributes to the growing body of research on technology integration in math education by providing empirical evidence for the efficacy of structured, teacher-mediated online programs, such as AN. Unlike many studies that single out technology as an independent variable in student learning, this research highlights the critical synergy between digital platforms, pedagogical methods, and teacher professionalization. The findings demonstrate that technology is not a cause of performance improvement in and of itself; rather, it is the strategic coordination of technology, as managed by teachers, that results in substantial learning improvements.

One of the most intriguing conclusions in this study is the subtle way that teachers utilized AN—not as a replacement for teaching but as a pedagogical aid that takes advantage of engagement, conceptual understanding, and individualized learning. This is supported by the NCTM framework, which views technology as a necessary yet strong auxiliary to the learning process. Educators were pedagogically flexible, favoring both student-centered (e.g., guided walk-throughs) and teacher-centered (e.g., explain-and-discuss exercises) approaches in AN integration. These dual approaches highlight the need for adaptive pedagogy to meet diverse learning styles and skill levels.

The research results persist in demonstrating the worth of structured technology use in mathematics education. That AN engagement and Algebra I EOC scores are positively correlated means that regular, guided interaction with the platform—rather than incidental or unstructured usage—is the path to maximizing learning outcomes. Schools that developed regular engagement with AN through student logins, video participation, and professional teacher training reported pass rates considerably higher. This corroborates the contention that well-supported, sustainable technology integration leads to improved performance, echoing evidence in digital learning [12], [29], [43]–[48].

One of the greatest contributions of this study is arguably its reaffirmation of the irreplaceable value that teachers bring to digital learning environments. The results confirm that technology alone is insufficient to spur student achievement—it must be situated within the framework of organized, research-driven pedagogical practice. Schools with high teacher engagement in AN reported better student outcome, emphasizing the importance of teacher agency in learning. This is corroborated by the instrumental orchestration theory, which purports that technology is most effective when purposively designed and led by educators [49]–[52]. Moving beyond passive learner interaction with digital technology, this study suggests that mathematics educators need to be digital learning architects, designing purposeful and dynamic learning experiences rather than merely offering access to technology.

Furthermore, the study extends existing technology acceptance model (TAM) research by demonstrating that teacher beliefs, digital self-efficacy, and professional development affect not only teachers' adoption of technology but also student learning outcomes and engagement. This finding supports Salami and Spangenberg [53], who proposed that perceived usefulness and simplicity of use impact technology adoption. More recent studies [54], [55] have reinforced that teachers' self-efficacy and attitudes toward technology significantly impact their willingness to integrate digital tools into classroom instruction.

This brings new opportunities to investigate the impact of teachers' attitudes, confidence, and professional development experiences on the efficacy of digital technology in mathematics instruction. Understanding these aspects can help to design more targeted professional development activities, resulting

in more successful technology-enhanced pedagogy. In terms of equity, this study also recognizes digital access disparities as a predictor of learning outcomes. Although technology can potentially equalize education disparities, variation in AN use between schools indicates that digital equity challenges persist. Concerns of device availability, internet accessibility, and the support provided by institutions have a major impact on how effectively students react to online learning platforms. Addressing such disparities through targeted interventions—such as subsidized access to technology, digital literacy training, and professional teacher development could ensure that all students have the opportunity to benefit from digital learning innovations regardless of socioeconomic status.

Overall, this study not only confirms the promise of blended learning approaches to mathematics education but also yields new insights into the circumstances under which digital tools can be made to add up to measurable academic gains. Ongoing research needs to continue investigating optimum digital learning methods, teacher training models, and the long-term impact of planned technology integration on student achievement. By ongoing refinement of the pedagogical models for online learning, we can achieve the full potential of technology to facilitate equitable and effective math instruction.

While the promising findings, this study has some limitations that need to be addressed through subsequent research. First, while the study assessed AN's impact at school level, the study did not investigate individual learners' performance in depth. It would be helpful to have more precise analysis through student-level data to make an even stronger relationship between the utilization of AN and individual learning processes. Additionally, while socioeconomic factors were considered, the extent to which economic disparities impact technology uptake remains open to question. More refined analysis with variables like household income, high-speed internet access, and parental support would be more comprehensive regarding digital equity issues.

Another main limitation is that there is no in-depth discussion of how different teaching styles influence student performance in using AN. While this study acknowledges the worth of student-initiated and teacher-initiated approaches, future research must examine what instructional methods work best with different groups of students. For instance, longitudinal examinations of the effects of daily, weekly, and last-minute AN participation may reveal optimal patterns of use. In turn, comparing student achievement in varying instruction formats—flipped classrooms versus traditional lecture-based instruction—would help further clarify best practices for integrating digital tools into math instruction.

Furthermore, the study emphasizes the importance of teacher professional development for effective AN implementation. Additional research, however, is necessary to learn about the impact of various training models on teachers' sustained use of technology in the long term. Experimental studies comparing different professional development methods—workshops, peer mentoring, and continuous coaching—would clarify the methods that produce the most potent improvements in incorporating digital tools. Additionally, qualitative classroom observation and teacher interview studies would offer an in-depth examination of how instructors manage technological implementation and modify instruction with experience.

Policy-wise, this study emphasizes the need for strategic interventions to mitigate the digital divide. As inequality in AN use was observed among schools, policymakers must invest in infrastructure, particularly in underprivileged areas. Device and high-speed internet access must be increased, but so must teacher preparation to incorporate these resources optimally. Subsequent research needs to examine how government and district-level initiatives can respond to digital disparities and improve learning outcomes.

At a theoretical level, the study corroborates instrumental orchestration theory by demonstrating that the effectiveness of technology depends on how it is incorporated into learning activities. The findings demonstrate that systematic and directed use of computer tools, and not passive student participation, yield the best results. This bears constructivist learning theories implications in that it illustrates that technology should be employed as a tool for active learning rather than content transfer.

In summary, although this research verifies the advantageous effect of AN on students' performance in Algebra I, more practical implications can be uncovered through deeper exploration of its findings. Subsequent research must aim at refining digital integration approaches, investigating most effective teaching models, and confronting structural inequalities that affect technology adoption in schools. In light of this, teachers and policymakers can optimize the potential of web-based learning platforms to improve mathematics education and overall student outcomes.

5. IMPLICATIONS OF FINDING AND FUTURE DIRECTION

The findings of this study provide some crucial insights for mathematics instruction, especially in relation to the integration of technology-based learning tools. One notable implication is the need for strategic technology integration. The results reinforce that tools such as AN should serve as complementary aids rather than as replacements for traditional instruction. Effective integration of such tools requires a structured and intentional approach, ensuring that technology is aligned with clear pedagogical goals.

Schools must therefore be deliberate in embedding these tools within well-thought-out instructional frameworks to maximize their impact.

Another major implication is the essential role of professional development. The study underscores that teacher training is critical for the optimal utilization of online resources for education. Without continuous support and skill development, even the most advanced tools may fall short of their potential. Schools and educational leaders must prioritize ongoing professional development initiatives that equip teachers with the competencies needed to navigate diverse digital environments and adopt best practices in blended and online learning.

Additionally, the report emphasizes the importance of equity in access to technology, which remains a substantial obstacle. Students from economically disadvantaged backgrounds often face limited access to digital devices and reliable internet connectivity. This digital divide can hinder the benefits of tools like AN, leading to disparities in educational outcomes. Policymakers, school administrators, and community leaders must work collaboratively to close these gaps, ensuring that both students and teachers have equal access to the necessary technological infrastructure and support services.

Furthermore, the study demonstrates the power of technology to increase student engagement and enable tailored learning. Online tools allow learners to progress at their own speed, revisit ideas as needed, and receive personalized guidance. This capability can improve learning experiences, particularly when adaptive technologies are employed to match the unique needs of individual students. Future implementations of digital resources should, therefore, prioritize personalization features that accommodate diverse learning styles and paces.

Looking ahead, this study's findings suggest a number of potential research options. One area in need of further exploration is the long-term impact of consistent use of AN and similar tools. While short-term improvements may be evident, it is critical to assess whether sustained engagement leads to enduring knowledge retention and better preparation for advanced mathematical study.

Another important research direction is the need for student-level analysis. The present study relied on school-level data, which may obscure individual differences and learning trajectories. Future studies should focus on tracking the performance of individual students to better understand how various subgroups respond to digital interventions and which factors contribute to their success.

Additionally, there is value in comparing different digital learning models. Investigating the relative effectiveness of teacher-centered versus student-centered approaches in digital contexts can yield insights into which pedagogies are most conducive to learning in technology-rich environments. Such comparisons will inform the design of more effective instructional strategies using platforms like AN.

Lastly, future research should explore the role of teacher networks and professional learning communities in enhancing the implementation of digital tools. The effectiveness of collaborative structures such as peer mentoring, teacher support groups, and professional development networks warrants close examination. These support systems may play a crucial role in helping educators adapt to technological innovations and share best practices across different teaching contexts. Addressing these future directions can support the development of more effective, inclusive, and equitable mathematics education programs. By building on the current findings, stakeholders, including teachers, policymakers, and researchers can work toward maximizing the benefits of digital learning tools for all learners.

6. CONCLUSION

This study provides empirical data that supports increased usage of AN is directly related to improved student performance on Algebra I EOC exams. Those schools with teachers who made a concerted effort to incorporate AN, particularly through workbook use and professional development, yielded significantly higher passing rates. The results highlight the importance of systematic technology integration, with teacher involvement being critical to maximum potential of the platform.

The findings are consistent with the instrumental orchestration theory, with an emphasis on technology supplementing, rather than replacing, conventional instruction. Though the study corroborates the benefits of AN, additional efforts must be conducted to determine its long-term impact, patterns of student engagement at the individual level, and digital equity as it pertains to access to online instructional resources. Promoting equal access to digital resources for all learners is still imperative to improving mathematics education outcomes.

ACKNOWLEDGMENTS

The authors would like to express their heartfelt gratitude to the participating schools and instructors for their contributions to this study.

FUNDING INFORMATION

The University of Johannesburg, South Africa financed this research. The funding body played no part in the study's design, data collection, analysis, or manuscript writing.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Olajumoke Olayemi Salami	✓	✓		✓	✓	✓		✓	✓	✓	✓		✓	
Erica Dorethea Spangenberg	✓	✓		✓	✓	✓		✓	✓	✓	✓	✓		

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors reported no potential conflicts of interest.

INFORMED CONSENT

Before data collection began, all study participants provided informed consent. Teachers were told about the research's goal, voluntary participation, and the possibility to withdraw at any moment. Data confidentiality and anonymity were rigorously enforced.

ETHICAL APPROVAL

This study followed the ethical requirements of the University of Johannesburg, South Africa. The university's Research Ethics Committee (REC) provided ethical approval.

DATA AVAILABILITY

The data supporting the study's conclusions are available upon reasonable request from the corresponding author [OOA]. Some constraints may apply to the entire dataset due to ethical reasons and participant confidentiality.

REFERENCES

[1] M. Fathurrohman, H. Nindiasari, N. Anriani, and A. S. Pamungkas, "Empowering mathematics teachers' ICT readiness with android applications for Bring Your Own Devices (BYOD) practice in education," *Cogent Education*, vol. 8, no. 1, p. 2002131, Jan. 2021, doi: 10.1080/2331186X.2021.2002131.

[2] M. A. Thohir, J. Jumadi, and W. Warsono, "Technological pedagogical content knowledge (TPACK) of pre-service science teachers: A Delphi study," *Journal of Research on Technology in Education*, vol. 54, no. 1, pp. 127–142, Jan. 2022, doi: 10.1080/15391523.2020.1814908.

[3] D. Thurm, S. Li, B. Barzel, L. Fan, and N. Li, "Professional development for teaching mathematics with technology: a comparative study of facilitators' beliefs and practices in China and Germany," *Educational Studies in Mathematics*, vol. 115, no. 2, pp. 247–269, Feb. 2024, doi: 10.1007/s10649-023-10284-3.

[4] A. Tlili, N. Padilla-Zea, J. Garzón, Y. Wang, K. Kinshuk, and D. Burgos, "The changing landscape of mobile learning pedagogy: A systematic literature review," *Interactive Learning Environments*, vol. 31, no. 10, pp. 6462–6479, Dec. 2023, doi: 10.1080/10494820.2022.2039948.

[5] O. S. Adesina, L. O. Obokoh, and O. O. Salami, "Does the high school external examination grades and the type of high school attended impact the academic performance of freshmen university students?" *STEM Education*, vol. 4, no. 4, pp. 328–345, 2024.

[6] A. Klemer, S. Rapoport, and H. Lev-Zamir, "The missing link in teachers' knowledge about common fractions division," *International Journal of Mathematical Education in Science and Technology*, vol. 50, no. 8, pp. 1256–1272, Nov. 2019, doi: 10.1080/0020739X.2018.1522677.

[7] N. H. Shah *et al.*, "Effect of students attitude towards mathematics on their mathematical achievement at secondary school level," *International Journal of Emerging Technologies in Learning (iJET)*, vol. 18, no. 12, p. 178, 2023, doi: 10.3991/ijet.v18i12.38765.

[8] P. J. Esperanza, C. Himang, M. Bongo, E. Selerio Jr., and L. Ocampo, "The utility of a flipped classroom in secondary Mathematics education," *International Journal of Mathematical Education in Science and Technology*, vol. 54, no. 3, pp. 382–415, Mar. 2023, doi: 10.1080/0020739X.2021.1957166.

[9] D. Fung, "The impacts of effective group work on social and gender differences in Hong Kong science classrooms," *International Journal of Science Education*, vol. 42, no. 3, pp. 372–405, Feb. 2020, doi: 10.1080/09500693.2020.1713419.

[10] M. Gök, "Mathematical Mystery in a Cultural Game," *World Journal of Education*, vol. 10, no. 6, pp. 64–73, Dec. 2020, doi: 10.5430/wje.v10n6p64.

[11] M. K. Olanrewaju and Y. Suleiman, "Effects of collaborative learning technique and mathematics anxiety on mathematics learning achievement among secondary school students in Gombe State, Nigeria," *Asian Journal of University Education*, vol. 15, no. 1, pp. 44–58, 2019.

[12] D. T. K. Ng, J. Su, J. K. L. Leung, and S. K. W. Chu, "Artificial intelligence (AI) literacy education in secondary schools: a review," *Interactive Learning Environments*, vol. 32, no. 10, pp. 6204–6224, Nov. 2024, doi: 10.1080/10494820.2023.2255228.

[13] E. Agyei, D. D. Agyei, and I. Benning, "Teaching Mathematics with Digital Technologies: A Situational Analysis of High School Teachers' Experiences in Ghana," *African Journal of Research in Mathematics, Science and Technology Education*, vol. 28, no. 1, pp. 57–70, Jan. 2024, doi: 10.1080/18117295.2023.2265241.

[14] National Council of Teachers of Mathematics (NCTM), *Principles and standards for school mathematics*. Reston, VA: NCTM, 2023. [Online]. Available: https://www.nctm.org/Standards-and-Positions/Principles-and-Standards/?utm_source

[15] National Council of Teachers of Mathematics (NCTM), *Principles to action: Ensuring mathematical success for all*. Reston, VA: NCTM, 2024. [Online]. Available: https://www.nctm.org/PtA/

[16] O. O. Noah, "Effect of Computer Game-Based Instructional Strategy on Students' Learning Outcome in Mathematics," *Journal of Education, Society and Behavioural Science*, vol. 29, no. 4, pp. 1–15, Apr. 2019, doi: 10.9734/jesbs/2019/v29i430113.

[17] National Mathematics Advisory Panel (NMAP), "Foundations for Success: The Final Report of the National Mathematics Advisory Panel," 2023. [Online]. Available: https://files.eric.ed.gov/fulltext/ED500486.pdf

[18] N. R. Mater *et al.*, "The effect of the integration of STEM on critical thinking and technology acceptance model," *Educational Studies*, vol. 48, no. 5, pp. 642–658, Sep. 2022, doi: 10.1080/03055698.2020.1793736.

[19] V. S. Zambak and A. M. Tyminski, "Examining mathematical technological knowledge of pre-service middle grades teachers with Geometer's Sketchpad in a geometry course," *International Journal of Mathematical Education in Science and Technology*, vol. 51, no. 2, pp. 183–207, Feb. 2020, doi: 10.1080/0020739X.2019.1650302.

[20] L. N. Safrida, T. B. Setiawan, Susanto, E. Yudianto, R. Ambarwati, and I. W. S. Putri, "Integrating GeoGebra into geometry space learning: a lesson from traditional cultural festival Tumpeng Sewu," *Journal of Physics: Conference Series*, vol. 1465, no. 1, p. 012046, Feb. 2020, doi: 10.1088/1742-6596/1465/1/012046.

[21] Y. Zhang and Q. Wang, "Content learning opportunities, computer-based instruction, and students' mathematics and science achievement," *International Journal of Mathematical Education in Science and Technology*, vol. 51, no. 8, pp. 1164–1180, Nov. 2020, doi: 10.1080/0020739X.2020.1717659.

[22] X. Li, Y. Zhou, and T. T. Wijaya, "The effect of haw Gent dynamic mathematics software on mathematics achievement: A meta-analysis," *Al-Jabar: Jurnal Pendidikan Matematika*, vol. 13, no. 1, pp. 175–188, Jun. 2022, doi: 10.24042/ajpm.v13i1.11711.

[23] R. E. Slavin, A. C. K. Cheung, and T. Zhuang, "How Could Evidence-Based Reform Advance Education?" *ECNU Review of Education*, vol. 4, no. 1, pp. 7–24, Mar. 2021, doi: 10.1177/2096531120976060.

[24] D. Sun, Y. Zhan, Z. H. Wan, Y. Yang, and C.-K. Looi, "Identifying the roles of technology: a systematic review of STEM education in primary and secondary schools from 2015 to 2023," *Research in Science & Technological Education*, vol. 43, no. 1, pp. 1–25, Aug. 2023, doi: 10.1080/02635143.2023.2251902.

[25] Q. Yu, B. Li, and Q. Wang, "The effectiveness of 3D holographic technology on students' learning performance: a meta-analysis," *Interactive Learning Environments*, vol. 32, no. 5, pp. 1–13, Oct. 2022, doi: 10.1080/10494820.2022.2124424.

[26] M.-S. Chiu, "Linear or quadratic effects of ICT use on science and mathematics achievements moderated by SES: conditioned ecological techno-process," *Research in Science & Technological Education*, vol. 40, no. 4, pp. 549–570, Oct. 2022, doi: 10.1080/02635143.2020.1830270.

[27] I. Gurevich and M. B. Ben-Av, "How do students assess the impact of integrating digital technologies on the mathematics classroom?" *International Journal of Mathematical Education in Science and Technology*, vol. 54, no. 7, pp. 1288–1297, Aug. 2023, doi: 10.1080/0020739X.2023.2179949.

[28] N. Dahal, B. P. Pant, I. M. Shrestha, and N. K. Manandhar, "Use of GeoGebra in High School Mathematics: A Case of Geometric Transformation for Teaching and Learning," in *Recent Progress in Science and Technology*, G. Y. Sheu, Ed. Kathmandu: B. P. International, 2023, pp. 66–81, doi: 10.9734/bpi/rpst/v1/4476F.

[29] D. Joshi, K. Adhikari, J. Khanal, S. Balbase, and B. Khanal, "Developing and integrating digital resources in online mathematics instruction and assessment during Covid-19," *SSRN*, 2024, doi: 10.2139/ssrn.4879328.

[30] F. Albeshree, M. Al-Manasia, C. Lemckert, S. Liu, and D. Tran, "Mathematics teaching pedagogies to tertiary engineering and information technology students: a literature review," *International Journal of Mathematical Education in Science and Technology*, vol. 53, no. 6, pp. 1609–1628, Jun. 2022, doi: 10.1080/0020739X.2020.1837399.

[31] P. A. Goedl, G. B. Malla, and M. G. Sanders, "Impact of Video Lectures on Students' Performance and Analysis of Viewer Demographics in Online Courses," *American Journal of Distance Education*, vol. 38, no. 2, pp. 150–167, 2024.

[32] S. Vimbelo and A. Bayaga, "Transforming Mathematics Education in TVET Colleges Through Humanising Pedagogy: An Exploration of Teaching Approaches, Student Engagement, and Real-life Examples," *IETE Journal of Education*, vol. 65, no. 2, pp. 139–154, Jul. 2024, doi: 10.1080/09747338.2024.2324808.

[33] V. Jungić and A. Burazin, "On Experimental Mathematics and Mathematics Education," *The American Mathematical Monthly*, vol. 128, no. 9, pp. 832–844, Oct. 2021, doi: 10.1080/00029890.2021.1964275.

[34] R. Nyman, K. Bråting, and C. Kilhamn, "Can programming support mathematics learning? An analysis of Swedish lower secondary textbooks," *International Journal of Mathematical Education in Science and Technology*, vol. 56, no. 7, pp. 1261–1279, Jul. 2025, doi: 10.1080/0020739X.2024.2329345.

[35] M. de Vita, L. Verschaffel, and J. Elen, "The Power of Interactive Whiteboards for Secondary Mathematics Teaching: Two Case Studies," *Journal of Educational Technology Systems*, vol. 47, no. 1, pp. 50–78, Sep. 2018, doi: 10.1177/0047239518767112.

[36] S. O. Akinoso, F. O. Olafare, and Z. B. Oye-Akinoso, "Effect of Collaborative Teaching on Secondary School Students' Achievement in and Attitude towards Mathematics," *International Journal of Research and Innovation in Applied Science (IJRIAS)*, vol. 6, no. 8, pp. 1–5, 2021, doi: 10.51584/IJRIAS.2021.6801.

[37] A. E. Smale-Jacobse, A. Meijer, M. Helms-Lorenz, and R. Maulana, "Differentiated Instruction in Secondary Education: A Systematic Review of Research Evidence," *Frontiers in Psychology*, vol. 10, Nov. 2019, doi: 10.3389/fpsyg.2019.02366.

[38] I. K. Nti, F. U. Bawah, J. A. Quarcoo, and F. Kalos, "A Bibliometric Analysis of Soft Computing Technology Applications Trends and Characterisation in Educational Research: Africa," *Africa Education Review*, vol. 19, no. 3, pp. 55–77, May 2022, doi: 10.1080/18146627.2023.2284744.
[39] M. A. Rizqi, C. Sa'dijah, and S. Susiswo, "Development of Linear Equations e-Learning Media by Integrating GeoGebra in Google Sites," *Jurnal Pendidikan MIPA*, vol. 24, no. 2, pp. 481–492, 2023, doi: 10.23960/jpmipa/v24i2.pp481-492.
[40] Y. Yedilbayev, A. Sarybayeva, D. Zharylgapova, N. Shektibayev, I. Usembayeva, and B. Kurbanbekov, "Factors influencing future physics teachers' acceptance of information and communicative competence technologies: A survey study," *Cogent Education*, vol. 10, no. 1, p. 2212119, Dec. 2023, doi: 10.1080/2331186X.2023.2212119.
[41] Y. Park, B. Kim, H. Koh, and M. Martin, "Lessons from an Integrative Review of Special Education Research on Pedagogical Content Knowledge in South Korea," *International Journal of Disability, Development and Education*, vol. 70, no. 7, pp. 1275–1295, Nov. 2023, doi: 10.1080/1034912X.2022.2041559.
[42] A. Abadie and G. Imbens, "Simple and Bias-Corrected Matching Estimators for Average Treatment Effects," Technical Working Paper T0283, National Bureau of Economic Research (NBER), Oct. 2019, doi: 10.3386/t0283.
[43] L. Haleva, A. Hershkovitz, and M. Tabach, "Students' activity in an online learning environment for mathematics: the role of thinking levels," *Journal of Educational Computing Research*, vol. 59, no. 4, pp. 686–712, Jul. 2021, doi: 10.1177/0735633120972057.
[44] M. N. Kholid *et al.*, "A systematic literature review of Technological, Pedagogical and Content Knowledge (TPACK) in mathematics education: Future challenges for educational practice and research," *Cogent Education*, vol. 10, no. 2, p. 2269047, Dec. 2023, doi: 10.1080/2331186X.2023.2269047.
[45] P. Morsch, "Capabilities and Competences for Strategic Decision Making in Digital World," in *35th Bled eConference Digital Restructuring and Human (Re)action*, 2022, pp. 759–775, doi: 10.18690/um.fov.4.2022.49.
[46] X. Liu, R. T. de Oliveira, M. Indulska, and M.-L. Verreynne, "Towards a Digital Capability Framework," in *Academy of Management Proceedings*, Aug. 2020, p. 18505, doi: 10.5465/AMBPP.2020.18505abstract.
[47] H. Weidner, L. Mez, and L. Okamura, "Findings of the Research Project," in *The Ecological Modernization Capacity of Japan and Germany: Comparing Nuclear Energy, Renewables, Automobility and Rare Earth Policy*, L. Mez, L. Okamura, and H. Weidner, Eds. Wiesbaden: Springer VS, 2020, pp. 185–205, doi: 10.1007/978-3-658-27405-4_13.
[48] D. C. Hague, E. Oakeshott, and A. Strain, "The Findings," in *Devaluation and Pricing Decisions: A Case Study Approach*, 1st ed., D. C. Hague, E. Oakeshott, and A. Strain, Eds. London: Routledge, 2022, pp. 154–197, doi: 10.4324/9781003261032-9.
[49] C. H. Perera, R. Nayak, and L. V. T. Nguyen, "Discussion," in *Social Media Marketing and Customer-Based Brand Equity for Higher Educational Institutions: Case of Vietnam and Sri Lanka*, C. H. Perera, R. Nayak, and L. V. T. Nguyen, Eds. Singapore: Springer Nature Singapore, 2022, pp. 217–245, doi: 10.1007/978-981-19-5017-9_7.
[50] C. Perrotta and M. A. Evans, "Orchestration, power, and educational technology: A response to Dillenbourg," *Computers & Education*, vol. 69, pp. 520–522, Nov. 2013, doi: 10.1016/j.compedu.2013.04.007.
[51] L. P. Prieto, Y. Dimitriadis, J. I. Asensio-Pérez, and C.-K. Looi, "Orchestration in learning technology research: evaluation of a conceptual framework," *Research in Learning Technology*, vol. 23, p. 28019, Sep. 2015, doi: 10.3402/rlt.v23.28019.
[52] S. L. Costa, C. Costa, F. Martins, and J. B. Lopes, "Instrumental Orchestration in the Primary School and the Use of Digital Resources to Link STEM and Art: Systematic Literature Review," in *International Conference on Technology and Innovation in Learning, Teaching and Education (TECH-EDU 2022)*, 2022, pp. 193–210, doi: 10.1007/978-3-031-22918-3_15.
[53] O. O. Salami and E. D. Spangenberg, "Assessing the role of online mathematics tools in enhancing student learning and engagement," *Educational Technology Quarterly*, vol. 2025, no. 1, pp. 67–85, Mar. 2025, doi: 10.55056/etq.874.
[54] T. Teo, G. Sang, B. Mei, and C. K. W. Hoi, "Investigating pre-service teachers' acceptance of Web 2.0 technologies in their future teaching: a Chinese perspective," *Interactive Learning Environments*, vol. 27, no. 4, pp. 530–546, May 2019, doi: 10.1080/10494820.2018.1489290.
[55] R. H. Fazio, J. R. Eiser, and N. J. Shook, "Attitude formation through exploration: Valence asymmetries," *Journal of Personality and Social Psychology*, vol. 87, no. 3, pp. 293–311, Sep. 2004, doi: 10.1037/0022-3514.87.3.293.

BIOGRAPHIES OF AUTHORS

Olajumoke Olayemi Salami is a postdoctoral researcher in the Department of Science and Technology Education, University of Johannesburg, South Africa. She is a lecturer at the Federal University Oye Ekiti, Nigeria. Her research interests include curriculum instruction in mathematics education. She can be contacted at email: olajumokes@uj.ac.za.

Erica Dorethea Spangenberg is a professor of mathematics education in the Department of Science and Technology Education, University of Johannesburg, South Africa. Her research interest includes affective constructs in teaching and learning mathematics via technology. She can be contacted at email: ericas@uj.ac.za.